World Journal of Urology (2021) 39:1257–1262
https://doi.org/10.1007/s00345-020-03287-9

ORIGINAL ARTICLE

Effects of irrigation parameters and access sheath size on the intra-renal temperature during flexible ureteroscopy with a high-power laser

Yasser A. Noureldin[1,2] · Ergina Farsari[3] · Panteleimon Ntasiotis[1] · Constantinos Adamou[1] · Athanasios Vagionis[1] · Theofanis Vrettos[4] · Evangelos N. Liatsikos[1,5] · Panagiotis Kallidonis[1]

Received: 17 April 2020 / Accepted: 28 May 2020 / Published online: 18 June 2020

Abstract

Objectives To investigate the effect of different laser power settings on intra-renal temperature (IRT) under different irrigation conditions during flexible ureteroscopy (FURS) in a live-anesthetized porcine model.

Methods Following ethics approval, 2 female pigs weighing ~ 28 kg were used. Under general anesthesia, a percutaneous access was obtained to fix a K-type thermocouple inside the pelvi-calyceal system for real-time recording of IRT during FURS without UAS, UAS-10/12, UAS-12/14, and UAS-14/16F. A high-power holmium laser was used and the IRT was recorded during laser activation for up to 60 s at a laser power of 20 W, 40 W, and 60 W under gravity irrigation and manual pump irrigation.

Results Under gravity irrigation, FURS without UAS was associated with hazardous IRT at a laser power as low as 20 W for as short as 20 s of laser activation. The IRT was rendered borderline when UAS was used. This UAS buffering effect disappeared with the use of higher laser-power settings (40 W and 60 W) with the maximal IRT exceeding 60 °C. Moreover, laser activation at 60 W was associated with very rapid increase in IRT within few seconds. Under pump irrigation, laser activation at the highest power setting (60 W) for 60 s was associated with a safe IRT, even without the use of UAS. The maximal IRT was below 45 °C.

Conclusion The use of high-power Ho:YAG laser carries potentially harmful thermal effect when used under gravity irrigation, even when large-diameter UAS is used. High-power settings (> 40 W) require high irrigation flow. The use of UAS is advisable to reduce the IRT and balance any intra-renal pressure increase.

Keywords Temperature · Pig · Laser · Ureteroscopy

Abbreviations

FURS	Flexible ureteroscopy
IRT	Intra-renal temperature
IRTmax	Maximal intra-renal temperature
RIRS	Retrograde intra-renal surgery
UAS	Ureteral access sheath
Ho:YAG	Holmium:yttrium–aluminum–garnet

✉ Evangelos N. Liatsikos
liatsikos@yahoo.com

1 Department of Urology, University of Patras, Patras, Greece

2 Department of Urology, Benha Faculty of Medicine, Benha University, Benha, Egypt

3 Department of Chemical Engineering, University of Patras, Patras, Greece

4 Department of Anesthesiology and ICU, University of Patras, Patras, Greece

5 Department of Urology, Medical University of Vienna, Vienna, Austria

Introduction

The advances in laser technology and miniaturization of instruments lowered the invasiveness of ureteroscopy and pushed it to occupy a leading role in the management of most ureteral and renal calculi [1, 2]. Holmium (Ho:YAG) is so far considered the gold standard modality for lithotripsy through the wide variety of characteristics that provide the ability to perform dusting, popcorning and fragmentation through both photo-thermal and photo-acoustic decomposition of stones [3, 4]. The new systems with pulse modulation (MOSES™ technology, Lumenis Ltd, Yokneam, Israel) and high power (up to 120 W) are expected to offer better delivery of laser energy with a potential to increasing efficiency of lithotripsy and decreasing stone retropulsion [4–6]. However, there is not enough data on the thermal changes within the kidney during the use of high-power laser. The elevation of intra-renal temperature may cause thermal injury that can have immediate to delayed adverse events. The wide range of incidence of ureteral strictures following lithotripsy (0.30–23.81%) gives an idea about the several causes that might occur intraoperatively and pass unnoticed; among these is the thermal injury [7]. Currently, there are few in vitro studies investigating the IRT resulting from high-power laser [8]. The current study investigated the effect of different laser power settings under different irrigation conditions during flexible ureteroscopy (FURS) in a live-anesthetized porcine model. The irrigation conditions included different configurations in terms of irrigation such as gravity irrigation and pump irrigation in combination with different access sheaths in size. Our hypothesis was that the use of the higher power laser settings would result in higher intra-renal temperatures (IRTs) and specific intra-operative configuration may be necessary to blunt the temperature rise.

Patients and methods

Study design

After obtaining ethics approval from the responsible state services, two female pigs weighing ~ 28 kg were recruited for this study.

Preparation of the pigs for the experiment

This was previously described in detail [9].

Operative setup and technique

The pig was put in supine position, tied to the operating table, and general anesthesia was initiated. The pig was prepped for diagnostic cystoscopy in order to identify the ureteral orifices and insert a 0.035 sensor guidewire (*HiWire™ Nitinol Core Wire Guide, COOK Medical, Cook Ireland Ltd., Limerick, Ireland*) in each kidney under fluoroscopic guidance. A ureteral catheter was inserted over the wire in the renal pelvis and retrograde pyelography took place. The pig was then turned to prone position, and a percutaneous access was secured using 18-gauge puncture needle under fluoroscopic guidance using bull's eye technique. One K-type insulated flexible metal thermocouple was fixed in the middle calyx of the kidney (right or left) using a custom-made configuration. This configuration consisted of 18F Silicon balloon nephrostomy (*COOK Medical, Cook Ireland Ltd., Limerick, Ireland*) though which the metal end of the thermocouple was inserted, and a 22F access sheath (Fig. 1). The balloon of the urethral catheter was inflated with 5 ml to fix the nephrostomy and the thermocouple inside the access sheath while providing watertight sealing of the percutaneous tract. The pig was then set to supine position. Insertion of Super stiff guidewire (*Amplatz Super Stiff™, Boston Scientific, Heredia, Costa Rica*) through each of the ureteral catheters in each kidney followed. The last step facilitated

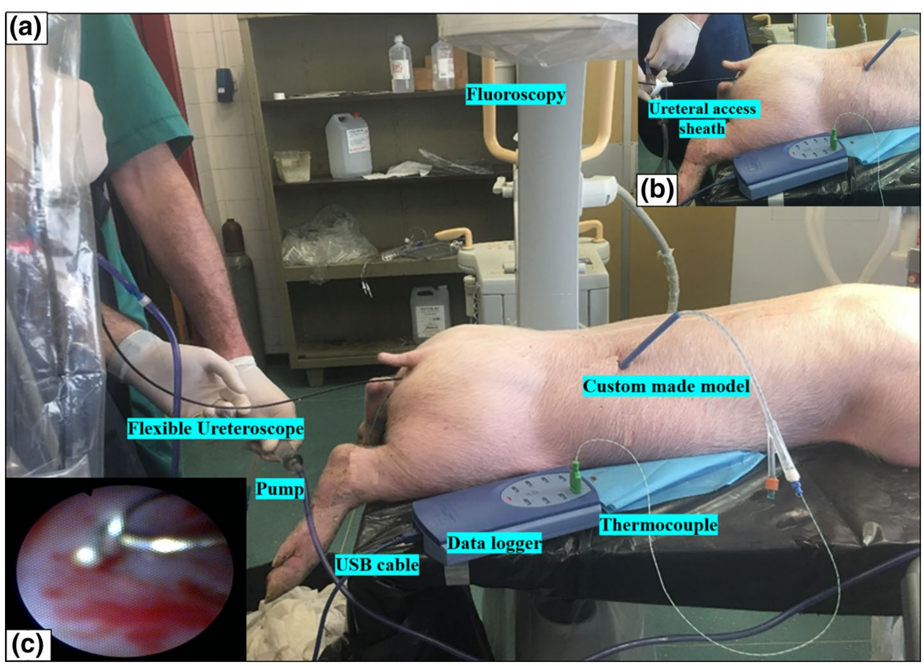

Fig. 1 **a** The setup for measuring of intra-renal temperature (IRT) during RIRS under forced irrigation using manual pump. **b** Measuring the IRT while using different size UAS. **c** Endoscopic view of the metal thermocouple during RIRS

the insertion of either the ureteral access sheath (UAS) or the flexible ureteroscope in the course of the experiment.

Thermocouple and data logger

The thermocouple used was SE001 from (*Pico Technologies, Cambridgeshire, UK*). It has an exposed junction and 0.3-mm twisted pair conductor and fiberglass insulated. It has a tip diameter of 1.5 mm and can record a temperature range from − 60 °C to + 350 °C (Fig. 1). The thermocouple was connected to a data logger (*TC08, Pico Technologies, Cambridgeshire, UK*) for real-time temperature measurements (Fig. 1). The data logger has 8 channels that can support all popular thermocouple types and can measure temperature from − 270 to + 1820 °C with high resolution and accuracy. It can record up to 10 measurements per second and comes with a USB cable for connecting with laptop. In this study the data acquisition rate was set at 1 count/s.

Measurement of IRT

Under gravity irrigation while the bag at 1 m over the table, one 200 µm laser fiber (*Lumenis Ltd, Yokneam, Israel*) was activated in the center of the calyx for 60 s while performing FURS using Flex-X2 Flexible Ureteroscope *(Karl Storz, Tüttlingen, Germany)* without UAS, UAS 10/12Fr, UAS 12/14Fr, and UAS 14/16Fr (*Flexor® Ureteral Access Sheath with AQ® Hydrophilic Coating, COOK Medical, Cook Ireland Ltd., Limerick, Ireland*) at a laser power of 20 W, 40 W, and 60 W using the Lumenis Pulse P120H holmium laser system (*Lumenis Ltd, Yokneam, Israel*) under gravity irrigation and manual pump irrigation. Irrigation fluid was at room temperature (measured at approximately 25 °C). The manual irrigation had a rate of 1 pump every 3 s. The cut-off value for a hazardous IRT max was considered 54 °C based on previous work [10].

Results

Gravity irrigation

FURS without the use of UAS was associated with a rise in IRT to hazardous values even for the lowest laser power (20 W) after a short period of treatment (~ 20 s). At 20 W power setting, the use of UAS improved the temperature evolution and safe IRT values (< 54 °C) were detected during the whole process (Fig. 2a). Nevertheless, the positive effect of the UAS on IRT was eliminated for laser power equal to 40 W and 60 W regardless the UAS size (Figs. 2b and 3a), i.e., when UAS 12/14 was used the maximum IRT was detected equal to 63.4 °C at 40 W and equal to 74.5 °C at 60 W. It is worth noticing that as the laser power increased, the temperature was increasing in a faster pace. Thus, high temperature values exceeding the proposed safety threshold were detected for short periods of laser activation (< 10 s).

Manual pump irrigation

The use of the manual pump for irrigation compensated the temperature increase for the high-power settings. High temperatures reaching the threshold of 54 °C were not noted regardless of the laser power setting with or without the presence of a UAS (Figs. 3b, 4). There was a uniform initial increase in the temperature and then a plateau was achieved. Specifically, the higher power settings (40 W and 60 W) were close to a highest temperature of 45° without reaching it when UAS was not present (Fig. 4). The insertion of a UAS was related to even lower temperatures resulting in

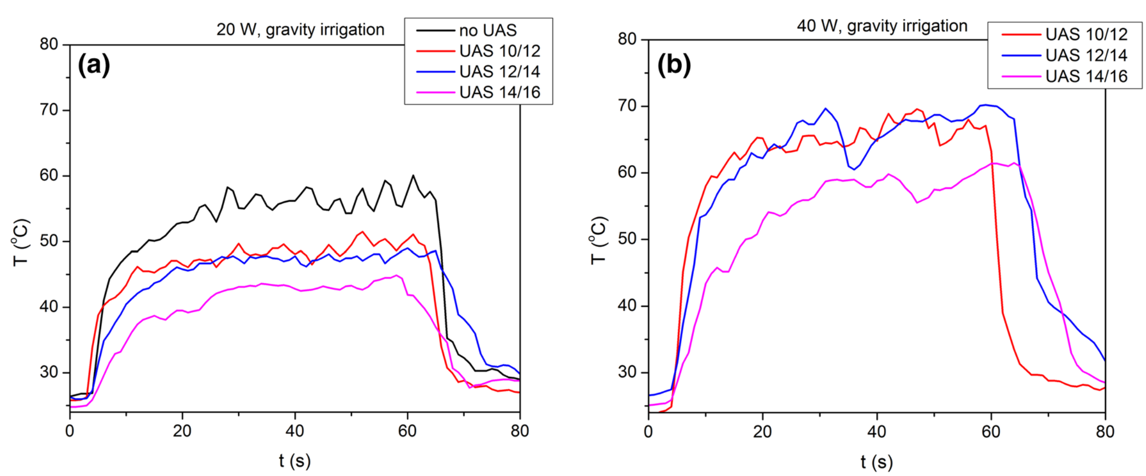

Fig. 2 **a** Activation of 200-µm laser fiber at 20 W for 60 s with the use of no UAS, UAS 10/12, UAS 12/14, and UAS 14/16 under gravity irrigation. **b** Activation of 200-µm laser fiber at 40 W for 60 s with the use of UAS 10/12, UAS 12/14, and UAS 14/16 under gravity irrigation

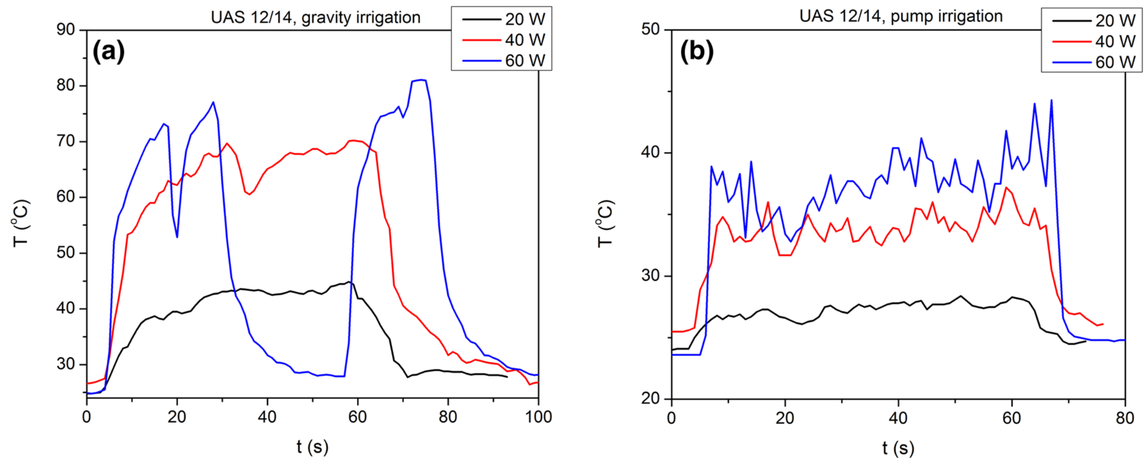

Fig. 3 **a** Activation of 200-μm laser fiber under gravity irrigation at 20, 40, and 60 W for 60 s with the use of UAS 12/14. **b** Activation of 200-μm laser fiber under pump irrigation at 20, 40, and 60 W for 60 s with the use of UAS 12/14

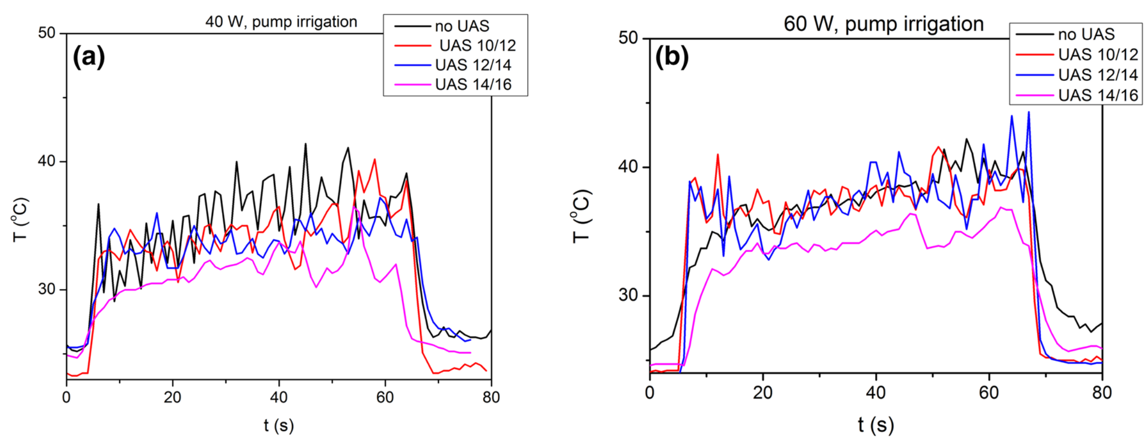

Fig. 4 **a** Activation of 200 μm laser fiber at 40 W for 60 s with the use of no UAS, UAS 10/12, UAS 12/14, and UAS 14/16 under pump irrigation**.** **b** Activation of 200-μm laser fiber at 60 W 60 s with the use of no UAS, UAS 10/12, UAS 12/14, and UAS 14/16 under pump irrigation

clearly safe temperatures below 40 °C in both 40 W and 60 W settings.

Discussion

The introduction of high-power laser with a wide variety of settings for lithotripsy in different modalities such as fragmentation, popcorning and dusting, have revolutionized the way stones are managed and this will reflect on the indications of flexible ureteroscopy in management of urolithiasis in the upcoming years. However, the knowledge on the most appropriate settings for the safe and effective use of a high-power laser is still lacking. The current study attempted to provide clues on the temperature that could develop in the irrigation fluid when a high-power laser is activated in an in vivo porcine model. Different operative configurations in terms of irrigation and the presence of UAS were investigated in conjunction to different laser power settings.

Previous studies showed that denaturation of the urinary tract proteins occurs at 43 °C [11] and coagulative tissues necrosis happens at a temperature of 54 °C in porcine kidney [10]. A reference temperature of 54 °C was used for thermal injury. Considering the threshold, the lack of forced irrigation is clearly a hazardous intraoperative configuration in any of the investigated power settings and should be probably avoided in the clinical setting (Fig. 2). The insertion of a UAS resulted in IRTs above 45 °C for the 10/12Fr and 12/14Fr UASs while the use of 14/16Fr UAS exhibited IRTs marginally reaching the 43 °C margin which could be related to the initiation of tissue damage (Fig. 2a). The 40 W and 60 W settings produce significantly more heat which result in rapid development of high temperatures even when a UAS is present. It seems that any effect in the improvement of the irrigation rate is diminished by the increased production of heat. Thus, gravity irrigation in combination with power settings higher than 20 W could not be recommended even when a UAS is present (Figs. 2b, 3a).

The correlation of irrigation conditions and temperature development during FURS has been previously investigated in vitro [8, 12, 13]. In a study by Winship et al. a model simulating the normal ureter and renal pelvis was used for performing FURS with UAS 11/13F with antegrade irrigation flow. The thermocouple was put close to a 365-µm laser fiber activated for 45 s at a power 3.6 W, 6.4 W, 10 W, 16 W and 20 W, using irrigation pressures of 0, 100, 200 mmHg. The recorded temperature exceeded 43 °C under irrigation pressure of 200 mmHg while using laser power of 10 W for 15 s, 16 W for 3 s, and 20 W for 2 s. Furthermore, the temperature exceeded the threshold during almost all power settings under irrigation pressure of 100 and 0 mmHg. Despite the limitations of study, it emphasized the fact that the higher the laser power the higher the IRT and the higher the irrigation pressure the lower the IRT [12].

In another study, three in vitro tissue models simulating the renal calyx, pelvis, and the ureter were created and used for recording the IRT with laser power settings between 5 and 40 W. The irrigation flow rates ranged between 0 and 40 mL/min. The investigation showed that the higher laser power corresponds to higher the IRT and higher irrigation pressure to lower IRT [13]. A study in the same topic has been also reported by Hein et al. The authors used a post-mortem porcine kidney placed in a 37 °C water bath as a model to measure thermal changes during FURS at Ho:YAG laser power settings between 5 and 100 W under various irrigation rates (0–100 mL/min) using thermocouple placed near the laser fiber. Potentially harmful thermal changes can be reached with insufficient irrigation and they devised the following formula to calculate the approximate ΔT for irrigation rates $\geq$ 30 ml/min: "$\Delta T = 15$ K × (power [W]/irrigation [ml/min])" [14].

Despite our previous in vivo study revealing that the Ho:YAG laser at a power of 10 W and 20 W did not correlate to hazardous rises of IRT in porcine model [15], the current study proves the importance of pump irrigation to cool down IRT when a high-power Ho:YAG laser is used. The combined effect of the laser power and the irrigation mode is illustrated in Fig. 3. In the figure, the evolution of the IRT is plotted for different laser power settings under gravity irrigation (Fig. 3a) and under pump irrigation (Fig. 3b) with the presence of a 12/14Fr UAS, which is a commonly used UAS for FURS. Under gravity irrigation the IRT reaches hazardous values at 40 W and 60 W after a short period of treatment (30 s for 40 W and 5 s for 60 W). Under forced irrigation, the IRT remains within safe limits even after prolonged treatments (60 s). The forced irrigation maintains safe IRTs even after 60 s of continuous activation regardless the size of the UAS (Fig. 4) and the laser power. It should be noted that there is a trend for higher IRTs as the laser power setting increases without exceeding the safety limits. Moreover, larger UASs seem to be related with lower IRTs. These results are in agreement with a recent in vivo study in the porcine model [6]. The activation of Ho:YAG laser at a power of 40 W was associated with IRT of 84.8 °C without irrigation, 63.9 °C under medium irrigation and 43.6 °C under high irrigation. Forced irrigation is not unrelated to adverse events, the rise in intra-renal pressure during pump irrigation might expose the patients to a higher risk of post-operative fever and sepsis [9, 16–18]. The use of a UAS is related to better irrigation condition and reduction of intra-renal pressures [16, 19]. Considering the above, it could be advocated that forced irrigation is mandatory when power settings above 40 W are going to be used intra-operatively and the use of a UAS could be strongly recommended for optimal safety conditions.

To our knowledge, this is the first in vivo study investigating the IRT during FURS under a variety of different laser power settings and intra-operative configurations. Nonetheless, limitations of the study are present. First, it is difficult to keep the laser fiber at the same distance from the thermocouple all the time. An anesthetized pig in mechanical ventilation represents a dynamic configuration which is closer to the clinical setting than any in vitro or ex vivo model and could be related with minor fluctuations in the real-time measurements. The repeated measurements showed consistent effects and the results should be considered as reliable. Second, it is not expected to extend the laser activation for 60 s in real clinical practice. Especially, the use of high-power settings (over 40 W) in the clinical practice is related to dust production which significantly compromises the intra-operative visibility and consequently results in pausing of laser activation. The authors could advocate that this phenomenon would further contribute to the reduction of IRT. Third, the laser was not activated in stone. It could be expected that fragmentation of the stone could result in adsorption of energy by the stone and less energy dispersion in the irrigation fluid. As a result, the IRT could have been lower with concomitant stone fragmentation. Thus, the current results probably represent the worst-case scenario for high-power holmium laser lithotripsy in each of the investigated operative configurations.

On the contrary, this study enjoys several strengths such as the experimental scenarios were very close to the clinical scenarios using the same instruments within the same environment. The heatsink effect of renal blood flow is present in a live, anesthetized pig. Moreover, the use of very sensitive flexible metal thermocouples within the custom-made mode to keep the thermocouple fixed all time during the experiment gives credibility to our data. Although any experimental setting is related to limitations, the current study provides necessary information for the safe use of new technologies employed in the everyday urological practice.

Conclusion

The use of high-power Ho:YAG laser carries potentially harmful thermal effect when used under gravity irrigation, even when large-diameter UAS is used. High-power settings (> 40 W) of the laser require high irrigation flow which can be achieved by a manual pump. The use of a UAS is also advisable to reduce the IRT and to balance any intra-renal pressure increase.

Acknowledgements This study was partially funded by a one-year scholarship from the European Urological Scholarship Program (EUSP) to Dr. Yasser Noureldin.

Author contributions YAN: study design, data collection, data analysis, manuscript writing. EF: manuscript writing. PN: data collection. CA: data collection. AV: data collection. TV: data collection. EL: study design, data collection, data analysis, manuscript editing. PK: study design, data collection, data analysis and manuscript editing.

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

Ethical approval The responsible state services provided approval for conducting the experiment.

References

1. Türk C, Petřík A, Sarica K, Seitz C, Skolarikos A, Straub M et al (2016) EAU guidelines on interventional treatment for urolithiasis. Eur Urol 69(3):475–482
2. Rassweiler J, Rassweiler M-C, Klein J (2016) New technology in ureteroscopy and percutaneous nephrolithotomy. Curr Opin Urol 26(1):95–106
3. Noureldin YA, Kallidonis P, Liatsikos EN (2020) Lasers for stone treatment: how safe are they? Curr Opin Urol 30(2):130–134
4. Fried NM, Irby PB (2018) Advances in laser technology and fibre-optic delivery systems in lithotripsy. Nat Rev Urol 15(9):563–573
5. Elhilali MM, Badaan S, Ibrahim A, Andonian S (2017) Use of the moses technology to improve holmium laser lithotripsy outcomes: a preclinical study. J Endourol 31(6):598–604
6. Aldoukhi AH, Hall TL, Ghani KR, Maxwell AD, MacConaghy B, Roberts WW (2018) Caliceal fluid temperature during high-power holmium laser lithotripsy in an in vivo porcine model. J Endourol 32(8):724–729
7. Dong H, Peng Y, Li L, Gao X (2018) Prevention strategies for ureteral stricture following ureteroscopic lithotripsy. Asian J Urol 5(2):94–100
8. Aldoukhi AH, Ghani KR, Hall TL, Roberts WW (2017) Thermal response to high-power holmium laser lithotripsy. J Endourol 31(12):1308–1312
9. Noureldin YA, Kallidonis P, Ntasiotis P, Adamou C, Zazas E, Liatsikos EN (2019) The effect of irrigation power and ureteral access sheath diameter on the maximal intra-pelvic pressure during ureteroscopy: in vivo experimental study in a live anesthetized pig. J Endourol 33(9):725–729
10. He X, McGee S, Coad JE, Schmidlin F, Iaizzo PA, Swanlund DJ et al (2004) Investigation of the thermal and tissue injury behaviour in microwave thermal therapy using a porcine kidney model. Int J Hyperth: Off J Eur Soc Hyperth Oncol N Am Hyperth Group 20(6):567–593
11. van Rhoon GC, Samaras T, Yarmolenko PS, Dewhirst MW, Neufeld E, Kuster N (2013) CEM43°C thermal dose thresholds: a potential guide for magnetic resonance radiofrequency exposure levels? Eur Radiol 23(8):2215–2227
12. Winship B, Wollin D, Carlos E, Peters C, Li J, Terry R et al (2019) The rise and fall of high temperatures during ureteroscopic holmium laser lithotripsy. J Endourol 33(10):794–799
13. Maxwell AD, MacConaghy B, Harper JD, Aldoukhi AH, Hall TL, Roberts WW (2019) Simulation of laser lithotripsy-induced heating in the urinary tract. J Endourol 33(2):113–119
14. Hein S, Petzold R, Suarez-Ibarrola R, Müller P-F, Schoenthaler M, Miernik A (2020) Thermal effects of Ho:YAG laser lithotripsy during retrograde intrarenal surgery and percutaneous nephrolithotomy in an ex vivo porcine kidney model. World J Urol 38(3):753–760
15. Kallidonis P, Kamal W, Panagopoulos V, Vasilas M, Amanatides L, Kyriazis I et al (2016) Thulium laser in the upper urinary tract: does the heat generation in the irrigation fluid pose a risk? Evidence from an in vivo experimental study. J Endourol 30(5):555–559
16. Rehman J, Monga M, Landman J, Lee DI, Felfela T, Conradie MC et al (2003) Characterization of intrapelvic pressure during ureteropyeloscopy with ureteral access sheaths. Urology 61(4):713–718
17. Ng YH, Somani BK, Dennison A, Kata SG, Nabi G, Brown S (2010) Irrigant flow and intrarenal pressure during flexible ureteroscopy: the effect of different access sheaths, working channel instruments, and hydrostatic pressure. J Endourol 24(12):1915–1920
18. Guzelburc V, Balasar M, Colakogullari M, Guven S, Kandemir A, Ozturk A et al (2016) Comparison of absorbed irrigation fluid volumes during retrograde intrarenal surgery and percutaneous nephrolithotomy for the treatment of kidney stones larger than 2 cm. SpringerPlus 5(1):1707
19. Sener TE, Cloutier J, Villa L, Marson F, Buttice S, Doizi S et al (2016) Can we provide low intrarenal pressures with good irrigation flow by decreasing the size of ureteral access sheaths? J Endourol 30(1):49–55